

## SEMICONDUCTOR DEVICE

### BACKGROUND OF THE INVENTION

The present invention generally relates to a semiconductor device for processing a radio frequency (RF) signal, and more particularly relates to an RF device for amplifying power of an RF signal in a mobile communications unit such as a cellular phone.

In recent years, as mobile communications units, e.g., cellular phones, have been popularized, it has become more and more necessary to cut down on the costs of RF devices build in those mobile communications units. Although a known RF device has been implemented using multiple chips (each including a single power-amplifying transistor for an RF signal thereon), a state-of-the-art RF device is implemented using a single chip including multiple power-amplifying transistors thereon.

In this case, those transistors might sometimes affect each another electrically because not so large a space as that of a conventional device is allowed between the transistors. Therefore, there is a problem that the RF characteristic of the overall device degrades compared to the conventional RF device that is implemented using multiple chips.

To solve this problem, a technique of providing an RF

signal isolating groove between the adjacent transistors on the substrate of the RF device was developed.

Figures 7(a) and 7(b) are respectively a plan view of a known RF device including an RF signal isolating groove and a cross-sectional view of the device taken along the line VIIb-VIIb in Figure 7(a).

As shown in Figures 7(a) and 7(b), first and second power-amplifying FETs (field effect transistors) 202 and 203 are provided on a semiconductor substrate 201. And an RF signal isolating groove 204 is formed between the first and second FETs 202 and 203 in the semiconductor substrate 201. Also, each of the first and second FETs 202 and 203 includes source electrodes 205, a gate electrode 206 and a drain electrode 207.

The RF device shown in Figures 7(a) and 7(b) realizes an RF characteristic with rather good linearity, because the RF signal isolating groove 204 is formed between the two FETs 202 and 203 to suppress electrical interference between the FETs 202 and 203.

However, if the RF signal isolating groove 204 shown in Figures 7(a) and 7(b) is too shallow, the groove 204 might not function properly in suppressing the electrical interference. On the other hand, if the groove 204 is too deep, the semiconductor substrate 201 might be destroyed.

## SUMMARY OF THE INVENTION

It is therefore an object of the present invention to suppress electrical interference between adjacent ones of power-amplifying transistors in an RF semiconductor device, which is implemented by providing the transistors on a semiconductor substrate without destroying the substrate.

A first semiconductor device according to the present invention includes: a semiconductor substrate; at least two semiconductor components provided on the principal surface of the substrate; and multiple through holes, which pass from the principal surface through the backside of the substrate and are provided in a region of the substrate between the at least two components.

According to the present invention, the electrical interference of signals between the two components can be suppressed by the multiple through holes.

In one embodiment of the present invention, a gap between two adjacent ones of the through holes is preferably smaller than the thickness of the substrate because it was found that the effect of suppressing the electrical interference is particularly noticeable in that case.

In another embodiment of the present invention, the device preferably further includes a conductor film on the side faces of the through holes, because the signal shielding function can be further improved.

In this particular embodiment, the device preferably further includes a grounded wiring layer on the backside of the substrate and the conductor film formed on the side faces of the through holes are preferably connected to the grounded wiring layer, because the effect of suppressing the electrical interference can be particularly enhanced.

A second semiconductor device according to the present invention includes: a semiconductor substrate; at least two semiconductor components provided on the principal surface of the substrate; electrodes of the components provided on the substrate; a first group of through holes, which pass from the principal surface through the backside of the substrate and are provided in respective regions of the substrate under the electrodes; a first conductor film provided on the side faces of the first group of through holes; a second group of through holes, which pass from the principal surface through the backside of the substrate and are provided in a region of the substrate between the components; a second conductor film provided on the side faces of the second group of through holes; and a wiring layer, which is provided on the backside of the substrate and is in contact with the first and second conductor films.

According to this invention, the first and second conductor films are connected together through the wiring layer. Therefore, the electrical interference between the at least

two components can be suppressed effectively.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1(a), 1(b) and 1(c) are respectively a plan view  
5 of an RF device in a first embodiment of the present invention, a cross-sectional view of the device taken along the line Ib-Ib in Figure 1(a) and a cross-sectional view of the device taken along the line Ic-Ic in Figure 1(a).

Figure 2 is a graph illustrating the g/d ratio dependence of isolation between adjacent FETs obtained by the present inventors.  
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Figures 3(a), 3(b) and 3(c) are respectively a plan view of an RF device in a second embodiment of the present invention, a cross-sectional view of the device taken along the  
15 line IIIb-IIIb in Figure 3(a) and a cross-sectional view of the device taken along the line IIIc-IIIc in Figure 3(a).

Figures 4(a), 4(b) and 4(c) are respectively a plan view of an RF device in a third embodiment of the present invention, a cross-sectional view of the device taken along the  
20 line IVb-IVb in Figure 4(a) and a cross-sectional view of the device taken along the line IVc-IVc in Figure 4(a).

Figures 5(a), 5(b), 5(c) and 5(d) are respectively a plan view illustrating the principal surface of an RF device in a fourth embodiment of the present invention, a cross-sectional view of the device taken along the line Vb-Vb in  
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Figure 5(a), a cross-sectional view of the device taken along the line Vc-Vc in Figure 5(a) and a plan view illustrating the backside of the RF device.

Figure 6 is a plan view of a printed circuit board 14 on which the RF device 15 shown in Figures 5(a) through 5(d) is mounted.

Figures 7(a) and 7(b) are a plan view of a known RF device including an RF signal isolating groove and a cross-sectional view of the device taken along the line VIIb-VIIb in Figure 7(a), respectively.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

##### EMBODIMENT 1

Figures 1(a), 1(b) and 1(c) are respectively a plan view of an RF device in a first embodiment of the present invention, a cross-sectional view of the device taken along the line Ib-Ib in Figure 1(a) and a cross-sectional view of the device taken along the line Ic-Ic in Figure 1(a).

As shown in Figures 1(a) through 1(c), the RF device of this embodiment includes: a semiconductor substrate 1 made of a compound semiconductor (e.g., GaAs); and first and second FETs 2 and 3 (i.e., exemplary first and second active components) provided on the semiconductor substrate 1. Also, each of the FETs 2 and 3 includes source electrodes 5, a gate electrode 6 and a drain electrode 7.

This embodiment is characterized in that four through holes 9, which pass through the semiconductor substrate 1 in the thickness direction, are provided in a region between the two FETs 2 and 3 on the semiconductor substrate 1. In this  
5 embodiment, the thickness  $d$  of the semiconductor substrate 1 is  $100\mu\text{m}$  and a gap  $g$  between each adjacent pair of through holes 9 is  $50\mu\text{m}$  as shown in Figure 1(c). According to results of experiments carried out by the present inventors, it was found that  $g$  is preferably smaller than  $d$  to enhance the  
10 effect of suppressing electrical interference between the FETs 2 and 3 as will be described later. However,  $g$  does not have to be smaller than  $d$ .

According to this embodiment, by providing the multiple through holes 9 between the two FETs 2 and 3, the electrical  
15 interference between the FETs 2 and 3 can be suppressed. We also found that the electrical interference between the two FETs 2 and 3 is much more likely to be suppressed noticeably by appropriately adjusting the gap between each adjacent pair of through holes 9. In addition, if the diameter of the  
20 through holes 9 is adjusted, the semiconductor substrate 1 is much less likely to be destroyed while the through holes 9 are being opened or after the through holes 9 have been opened. Therefore, according to this embodiment, it is possible to prevent the semiconductor substrate 1 from being de-  
25 stroyed, and it is also possible to substantially eliminate

the electrical interference between the two FETs 2 and 3.

Figure 2 is a graph illustrating the  $g/d$  ratio dependence of isolation between adjacent FETs obtained by the present inventors. The ordinate represents a ratio (dB), at which the power of an RF signal input to the first FET 2 leaks to the adjacent second FET 3, as isolation. The graph in Figure 2 shows that the smaller the isolation represented as the ordinate, the lesser the degree of electrical interference. On the other hand, the abscissa represents a ratio of the gap  $g$  between each adjacent pair of through holes 9 to the thickness  $d$  of the semiconductor substrate 1 as shown in Figure 1(c).

As shown in Figure 2, by providing the through holes between the two FETs, the isolation is improved. We found that the isolation function is remarkable, and the power leaking from the first FET 2 to the second FET 3 decreases considerably particularly when the  $g/d$  ratio is 1 or less, (i.e., when  $g/d \leq 1$ ).

## EMBODIMENT 2

Figures 3(a), 3(b) and 3(c) are respectively a plan view of an RF device in a second embodiment of the present invention, a cross-sectional view of the device taken along the line IIIb-IIIb in Figure 3(a) and a cross-sectional view of the device taken along the line IIIc-IIIc in Figure 3(a).



As shown in Figures 3(a) through 3(c), the RF device of this embodiment includes: a semiconductor substrate 1 made of a compound semiconductor (e.g., GaAs); and first and second FETs 2 and 3 provided on the semiconductor substrate 1. Also, each of the FETs 2 and 3 includes source electrodes 5, a gate electrode 6 and a drain electrode 7. Further, through holes 8, which pass through the semiconductor substrate 1 in the thickness direction, are opened through portions of the semiconductor substrate 1 under the source electrodes 5, and a conductor film 10 is formed out of a gold plated layer with a thickness of about 2  $\mu\text{m}$  on the side faces of the through holes 8.

This embodiment is characterized in that the four through holes 9, which pass through the semiconductor substrate 1 in the thickness direction, are opened in a region of the substrate 1 between the two FETs 2 and 3, and that the conductor film 10 is also formed on the side faces of these through holes 9.

In this embodiment, the thickness  $d$  of the semiconductor substrate 1 is also  $100\mu\text{m}$  and a gap  $g$  between each adjacent pair of through holes 9 is also  $50\mu\text{m}$  as shown in Figure 3(c). That is to say, in this embodiment,  $g$  is also smaller than  $d$ . However,  $g$  does not have to be smaller than  $d$ .

According to this embodiment, by appropriately adjusting the gap between each adjacent pair of through holes 9, the

electrical interference between the two FETs 2 and 3 is much more likely to be suppressed as in the first embodiment. In addition, if the diameter of the through holes 9 is adjusted, the semiconductor substrate 1 is much less likely to be destroyed while the through holes 9 are being opened or after the through holes 9 have been opened.

Furthermore, according to this embodiment, the conductor film 10 is formed out of a gold plated layer, for example, on the side faces of the through holes 9. Therefore, the through holes 9 can have its function of reducing the RF leakage enhanced by the conductor film 10 and the electrical interference between the two FETs 2 and 3 is much more likely to be eliminated.

It should be noted that the through holes 9 can be opened while the through holes 8 are being opened under the source electrodes 5. Therefore, the number of process steps, e.g., photolithography or etching process, does not increase.

### EMBODIMENT 3

Figures 4(a), 4(b) and 4(c) are respectively a plan view of an RF device in a third embodiment of the present invention, a cross-sectional view of the device taken along the line IVb-IVb in Figure 4(a) and a cross-sectional view of the device taken along the line IVc-IVc in Figure 4(a).

As shown in Figures 4(a) through 4(c), the RF device of

1 this embodiment includes: a semiconductor substrate 1 made of  
2 a compound semiconductor (e.g., GaAs); and first and second  
3 FETs 2 and 3 provided on the semiconductor substrate 1. A  
4 grounded wiring layer 11 is formed over the entire backside  
5 of the semiconductor substrate 1 and the substrate 1 is  
6 mounted over a die pad 12 with the grounded wiring layer 11  
7 interposed therebetween. And each of the FETs 2 and 3 in-  
8 cludes source electrodes 5, a gate electrode 6 and a drain  
9 electrode 7. Further, through holes 8, which pass through the  
10 semiconductor substrate 1 in the thickness direction, are  
11 opened through portions of the substrate 1 under the source  
12 electrodes 5. And a conductor film 10 is formed out of a gold  
13 plated layer with a thickness of about 2  $\mu$ m on the side  
14 faces of the through holes 8. The source electrodes 5 and  
15 grounded wiring layer 11 are electrically connected together  
16 through the conductor film 10.

17 This embodiment is characterized in that the four  
18 through holes 9, which pass through the semiconductor sub-  
19 strate 1 in the thickness direction, are opened in a region  
20 of the substrate 1 between the two FETs 2 and 3, and that the  
21 conductor film 10 is also formed on the side faces of these  
22 through holes 9. The conductor film 10 on the side faces of  
23 these through holes 9 is also connected to the grounded wir-  
24 ing layer 11. Therefore, in this embodiment, the conductor  
25 film 10, formed on the side faces of the through holes 9, and

the source electrodes 5 are maintained at almost the same potential levels (i.e., around ground level) while the RF device is being operated.

In this embodiment, the thickness  $d$  of the semiconductor substrate 1 is also  $100\mu\text{m}$  and a gap  $g$  between each adjacent pair of through holes 9 is also  $50\mu\text{m}$  as shown in Figure 4(c). That is to say, in this embodiment,  $g$  is also smaller than  $d$ . However,  $g$  does not have to be smaller than  $d$ .

According to this embodiment, the electrical interference between the two FETs 2 and 3 is much more likely to be suppressed by the through holes 9. In addition, if the diameter of the through holes 9 is adjusted, the semiconductor substrate 1 is much less likely to be destroyed while the through holes 9 are being opened or after the through holes 9 have been opened.

Furthermore, according to this embodiment, the conductor film 10 is formed out of a gold plated layer, for example, on the side faces of the through holes 9. Therefore, the through holes 9 can have its function of reducing the RF signal leakage enhanced by the conductor film 10 and the electrical interference between the two FETs 2 and 3 is much more likely to be eliminated.

Moreover, in this embodiment, the conductor film 10 formed on the side faces of the through holes 9 and the source electrodes 5 are maintained at almost the same potential

levels (i.e., around ground level). Therefore, the conductor film 10 can further improve the function of shielding the RF power leakage from the FET 2 or 3 and the electrical interference between the two FETs 2 and 3 can be eliminated more effectively.

It should be noted that the through holes 9 can be opened while the through holes 8 are being opened under the source electrodes 5. Therefore, the number of process steps, e.g., photolithography or etching process, does not increase. In other words, there is no need to add the process of forming a member for grounding the source electrodes 5.

#### EMBODIMENT 4

Figures 5(a), 5(b), 5(c) and 5(d) are respectively a plan view illustrating the principal surface of an RF device in a fourth embodiment of the present invention, a cross-sectional view of the device taken along the line Vb-Vb in Figure 5(a), a cross-sectional view of the device taken along the line Vc-Vc in Figure 5(a) and a plan view illustrating the backside of the RF device.

As shown in Figures 5(a) through 5(c), the RF device of this embodiment includes: a semiconductor substrate 1 made of a compound semiconductor (e.g., GaAs); and first and second FETs 2 and 3 provided on the semiconductor substrate 1. Each of the FETs 2 and 3 includes source electrodes 5, a gate

electrode 6 and a drain electrode 7. Further, through holes 8, 81 and 82, which pass through the semiconductor substrate 1 in the thickness direction, are opened through portions of the semiconductor substrate 1 under the source electrodes 5, the gate electrode 6 and the drain electrode 7, respectively. And a conductor film 10 is formed out of a gold plated layer with a thickness of about 2  $\mu$ m on the side faces of the through holes 8, 81 and 82. Another four through holes 9, which also pass through the semiconductor substrate 1 in the thickness direction, are opened in a region of the substrate 1 between the two FETs 2 and 3. And the conductor film 10 is also formed on the side faces of these through holes 9.

As shown in Figure 5(d), a grounded wiring layer 11, two wiring regions 111 and another two wiring regions 112 are provided on the backside of the semiconductor substrate 1. The grounded wiring layer 11 surrounds not only the through holes 8 under the source electrodes 5 but also the through holes 9. Each of the wiring regions 111 surrounds the through hole 81 under the associated one of the gate electrodes 6. And each of the wiring regions 112 surrounds the through hole 82 under the associated one of the drain electrodes 7. Each pair of the source electrodes 5 and the grounded wiring layer 11 are electrically connected together through the conductor film 10 formed on the side faces of the through holes 8 under the pair of source electrodes 5. And the grounded wiring

layer 11 and the conductor film 10 formed on the side faces of the through holes 9 are electrically connected together. Also, each of the gate electrodes 6 and associated one of the wiring regions 111 are electrically connected together through the conductor film 10 formed on the side faces of the associated through hole 81. And each of the drain electrodes 7 and associated one of the wiring regions 112 are electrically connected together through the conductor film 10 formed on the side faces of the associated through hole 82.

10 In this embodiment, the four through holes 9, which pass through the semiconductor substrate 1 in the thickness direction, are opened in the region of the substrate 1 between the two FETs 2 and 3. And the conductor film 10, which is connected to the grounded wiring layer 11, is also formed on the side faces of these through holes 9. Therefore, the conductor film 10, formed on the side faces of the through holes 9, and the source electrodes 5 are maintained at almost the same potential levels (i.e., around ground level) while the RF device is being operated.

20 In this embodiment, the thickness  $d$  of the semiconductor substrate 1 is also  $100\mu\text{m}$  and a gap  $g$  between each adjacent pair of through holes 9 is also  $50\mu\text{m}$  as shown in Figure 5(c). That is to say, in this embodiment,  $g$  is also smaller than  $d$ . However,  $g$  does not have to be smaller than  $d$ .

25 Figure 6 is a plan view of a printed circuit board (PCB)

14 on which the RF device 15 shown in Figures 5(a) through 5(d) is mounted. As shown in Figure 6, a grounded wiring layer 13, gate lines 131 and drain lines 132 are provided on the principal surface of the PCB 14. The RF device 15 is mounted on the PCB 14 in such a manner that the grounded wiring layer 11 of the RF device 15 is connected to the grounded wiring layer 13 on the PCB 14, the wiring regions 111 of the RF device 15 are connected to the gate lines 131 on the PCB 14 and the wiring regions 112 of the RF device 15 are connected to the drain lines 132 on the PCB 14. By mounting the RF device 15 on the PCB 14 in this manner, an RF module can be formed.

According to this embodiment, in addition to the construction of the third embodiment, the gate electrodes 6 are connected to the gate lines 131 on the PCB 14 via the conductor film 10 formed on the side faces of the through holes 81 under the gate electrodes 6. And the drain electrodes 7 are connected to the drain lines 132 on the PCB 14 via the conductor film 10 formed on the side faces of the through holes 82 under the drain electrodes 7. Therefore, a voltage can be easily applied to these electrodes 5, 6 and 7 through the grounded wiring layer 13 and the gate and drain lines 131 and 132 formed on the PCB 14. That is to say, not only the effects of the third embodiment are attained but also the RF module, which is implemented by mounting the RF device 15 on



the PCB 14, can be smaller in size.

It should be noted that the through holes 9, 81 and 82 can be opened while the through holes 8 are being opened under the source electrodes 5. Therefore, the number of process steps, e.g., photolithography or etching process, does not increase. In other words, there is no need to add the process of forming a member for grounding the source electrodes 5.

It should also be noted that FETs, which are exemplary power amplifiers, are provided as semiconductor components in the foregoing embodiments, but bipolar transistors may be provided instead of the FETs.

Furthermore, when passive components, e.g., capacitors or conductors, are provided as the two semiconductor components, the function of reducing the electrical interference between these two semiconductor components can be obtained by providing the through holes of the present invention between the components.

Moreover, a semiconductor device including two semiconductor components is described in the foregoing embodiments. However, the present invention is applicable to a semiconductor device including three or more components. In that case, the through holes need to be provided between each pair of the components.